Chapter 3
SHORE PROTECTION PROJECTS

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Chapter V-3
Shore Protection Projects

V-3-1. Introduction

The main purpose of this chapter is to summarize alternatives and their functional design for shore protection. Coastal defense and stabilization works are used to retain or rebuild natural systems (cliffs, dunes, wetlands, and beaches) or to protect man's artifacts (buildings, infrastructure, etc.) landward of the shoreline. A secondary purpose is to review the many constraints that will influence the final design.

a. Major concerns for shore protection

(1) Storm damage reduction. Coastal storms generally cause damage by two mechanisms.

(a) Coastal floodings. On the Atlantic Ocean and Gulf of Mexico coasts, tropical storms (hurricanes) produce elevated water levels, (storm surge) that inundate and damage coastal property. Extra tropical storms (northeasters) along the eastern seaboard and other coasts also create high water and flood damage. Damage from coastal flooding is arguably greater than that due to high winds on the world's coasts.

- Following the devastating flood in 1953, the Dutch people began the Delta Project to raise the dikes and construct barriers (dams) across the estuarine openings to the North Sea. The last component was the Oosterschelde (Eastern Scheldt) storm surge barrier as displayed in an aerial view in Figure V-3-1a and a photograph of the movable gates in Figure V-3-1b. It is one of the largest coastal engineering projects ever completed in the world and a major engineering achievement.

- Inland flooding also disrupts traffic, business, medical services, and normal life to produce secondary, economic and social impacts.

(b) Wave damage. Elevated water levels also bring higher wave energy inland to damage upland development. Damage is a nonlinear function of wave height. On the West Coast, the elevated ocean surface of El Nino events coupled with high storm waves causes damage to marinas, piers, and coastal infrastructure.

(2) Coastal erosion mitigation. The second major concern is coastal erosion. Storms create short-term erosional events. Natural recovery after the storm and seasonal fluctuations may not be in balance to produce long-term erosion. Shore protection projects moderate the long-term average erosion rate of shoreline change from natural or manmade causes. Reduced erosion means a wider sediment buffer zone between the land and the sea. And consequently, erosion mitigation translates into storm damage reduction from flooding and wave attack. How natural shorelines remain stable and mitigate upland damage is explicitly reviewed in Part V-3-3-a. Use of the terms flood control and erosion control are discouraged. Complete control of coastal flooding and erosion is a myth that gives a false sense of security to the client, the general public, and the media. Man cannot control nature. There is always the chance for a more powerful storm than the level of shore protection provided within the design constraints. A reduction in potential levels of flooding and erosion, i.e., mitigation means storm damage reduction benefits and the need for a risk-based, design philosophy, as discussed herein.

a. Aerial view

b. Moveable gates

Figure V-3-1. Oosterschelde storm surge barrier (courtesy Rijkswaterstaat, The Netherlands)

(3) Ecosystem restoration. A new area of concern is the restoration of lost environmental resources such as wetlands, reefs, nesting areas, etc. In 1990, the U.S. Army Corps of Engineers was directed to also consider ecosystem restoration where a Federal project has contributed to ecosystem degradation. For this chapter, Corps civil works project objectives and special design constraints (economic, environmental, institutional, etc.) have been omitted. They have all been brought together in Part V-8. Where appropriate, differences between the Corps' design approach and a general design approach are discussed here.

b. Alternatives for shore protection.

(1) Overview. Figure V-3-2 (adapted from Gilbert and Vellinga 1990) schematically displays five alternative ways to mitigate the damage of coastal storms, namely, accommodation, protection, beach nourishment, retreat and of course, the do-nothing alternative. Civilization's artifacts at the coast are here represented by the lighthouse at a fixed reference line. Storm surge and storm erosion reduce the distance between the reference line and the sea. Sea level rise and historic, coastal erosion also reduce the distance, but at slower time scales. Beach nourishment accomplishes the same objective as the retreat option (i.e., increase the distance to the sea).

(a) Pope (1997) has a similar classification system summarized in Table V-3-1.

Table V-3-1 Classes of Management and Engineering Response for Shore Protection (Pope 1997)

Type	Common Phrase
1) Armoring	Draw the line
2) Moderation	Slow down the erosion rate
3) Restoration	Fill up the beach
4) Abstention	Do nothing
5) Adaptation	Live with it

(b) The protection category in Figure V-3-2 is divided into armoring (seawalls, bulkheads, etc.) for flooding and moderation (groins, breakwaters, etc.) for erosion mitigation and shoreline stabilization. Beach nourishment or restoration is sometimes called the soft alternative to the armored or hard alternative for shore protection. Figure V-3-3 displays the shift from hard to soft, beach nourishment projects over the past 50 years by the Corps of Engineers (from Hillyer 1996).

(c) For design, consider the following six types of alternatives, namely: armoring, beach stabilization (moderation) structures, beach nourishment, adaptation and retreat, combinations (and new technologies) and the with-no-project (abstention) alternative. Table V-3-2 summarizes these alternatives for coastal hazard mitigation including the sections where full discussions are presented.

(2) Armoring. Seawalls, bulkheads, and protective revetments for cliffs and dikes are the traditional types of armored shorelines. The cost of armoring is justified when flooding and wave damage in low areas threaten substantial human investment. On historic, eroding coasts, it must be expected that erosion will continue to diminish the width of the buffer strip between armored shoreline and the sea. If a recreational beach is present, periodic beach nourishment must be anticipated. Part V-3-2 gives functional design details

Table V-3-2
Alternatives for Coastal Hazard Mitigation

Approach	**Changes to the Natural, Physical System**							
Class	**Armoring Structures**			**Beach Stabilization Structures and Facilities**				
Type	**Seawall**	**Bulkhead**	**Dike/Revetment**	**Breakwaters**	**Groins**	**Sills**	**Vegetation**	**Groundwater Drainage**
Geometry (configurations) or location	• Vertical • Curved • Gravity	• Crib • Stepped/Terraced • Cantilevered • Tie-Backed	• Sloped	• Headland • Detached • Single • System • Submerged (reef-type)	• Normal • Angled • Single • System (field) • Notched • Permeable • Adjustable • Shaped (T or L)	• Shoreline • Submerged • Perched beach • Intertidal		• Beachdrain • Bluff dewatering • Interior drainage
Materials of construction	• Concrete • Rock	• Sheet-pile - steel - timber -concrete - aluminum	• Earth • Rock revetment • Geotextiles (bags) • Gabions	• Rock • Precast concrete units • Sheet-pile types - steel - concrete - timber - etc. • Geotextiles bags			• wetland • Submerged Aquatic Vegetation • Mangrove	• System of pipes and pumps with sumps
Discussion in found sections	**Part V-3-2**			**Part V-3-3**				
	V-3-2-a(1)	V-3-2-a(2)	V-3-2-a(1)	V-3-3-c V-3-3-d	V-3-3-e	V-3-3-f		V-3-5-b

(Continued)

Table V-3-2 (Concluded)

Changes to the Natural Physical System (continued)		Changes to Man's System			Changes in Both		No Change
Beach Restoration		**Adaptation and Accomodation**			**Combinations**		**Do Nothing**
Beach Nourishment	**Sand Passing**	**Flood Proofing**	**Zoning**	**Retreat**	**Structural and Restoration**	**Structural and Restoration and Adaptation**	
• Subaerial • Dune • Feeder • Profile • Underwater berms	• Bypassing • Bankpassing	• Elevated structures • Raise grade • Sandbags • Flow diversion	• Setbacks • Land use restrictions • Public lands (Institutional)	• Individuals • Communities • Infrastructure • Move structures	• Any combination of 1, 2, or 3 alternatives	• Any combination of all alternatives except retreat	Let nature take its course
• Borrow sites - offshore - land • Dredged material • Artificially made (crushed rock)	• Littoral traps • Smooth out hot-spots • Downdrift material returned updrift	• Single-family homes on timber piles					
Part V-4			V-3-4 V-3-4-b	V-3-4-c	V-3-5		V-3-6

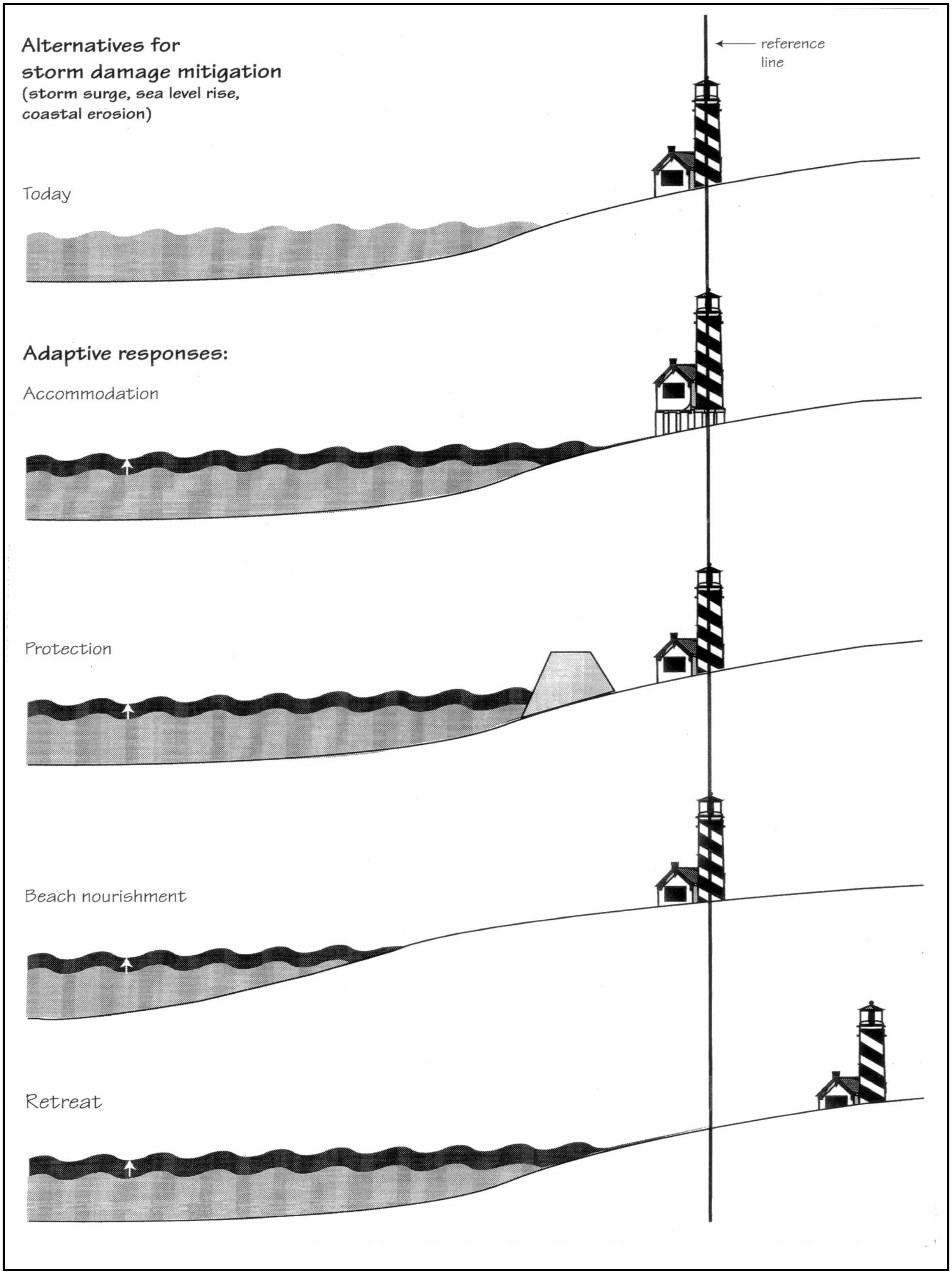

Figure V-3-2. Alternatives for shore protection

and summarizes knowledge on the interaction of armored shorelines and adjacent beaches. See also Engineer Manual 1110-2-1614, "Design of Coastal Revetments, Seawalls, and Bulkheads."

(3) Beach stabilization. Headland and nearshore breakwaters, groins, sills and reefs, and wetlands all moderate the coastal sediment transport processes to reduce the local erosion rate. These structures should be considered where chronic erosion is a problem due to the diminished sediment supply. They are often combined with beach nourishment to reduce downdrift impacts. Their purpose is to slow the loss of placed sand, not to trap sand from the littoral system and create more problems elsewhere. In many locations, their improper functional design, or construction without adding extra material, has produced adverse environmental impacts by starving the supply of sand to downdrift beaches. Their proper design is one of the great challenges of coastal engineering, and functional design aspects are found in Part V-3-3.

(4) Beach nourishment. Loose sediment material can be placed on the subaerial beach, as underwater mounds, across the subaqueous profile, or as dunes to rebuild the dunes. The soft alternative solution for shore protection is now the common alternative selected for a variety of reasons (constraints). Because of its importance, a separate chapter, Part V-4 contains all the details for design.

(5) Adaptation and retreat. Elevating structures, flood proofing, zoning restrictions, storm warning and evacuation planning are some of the types of coastal adaptation methods. Further details are in Part V-3-4-b. Retreat is permanent evacuation or abandonment of coastal infrastructure, and for communities subject to high erosion rates and flooding damages, this is always a possible alternative. Total costs and constraints of this alternative must include the environmental impact on the new site to where "retreat" takes place. In contrast to the engineering, decision-making process to determine the best alternative considering all the design constraints for each site, some advocate retreat as the only solution. Further discussion is in section Part V-3-4-c.

(6) Combinations and new technologies. In many locations, elevated structures combined with some type of armoring or shoreline stabilization structure together with beach nourishment are employed for shore protection. Nontraditional technologies (e.g., beach drains, geotextile bags, artificial breakwater structures, wetlands, etc.) are also being investigated in field experiments. Part V-3-5 gives more details.

(7) Do nothing. Finally, the option to allow continued erosion and storm damage with the expected, annual costs for this choice should be determined. The without project condition provides the basis for measuring the effectiveness to reduce the expected damages of each proposed alternative. Further details for estimating damage costs are in Part V-3-1-c. Part V-3-6 presents more general information on this option. See also Part VI-2-1 for more details regarding various subtypes of the armoring, shoreline stabilization, and beach nourishment alternatives. Each alternative must be considered under a wide variety of design constraints.

c. Design constraints.

One good definition of engineering is "design under constraint." Engineering is creating and designing what can be, but it is constrained by our understanding of nature, by economics (costs), by concerns of environmental impact, by institutional, social, legal issues and possibly by aesthetics. Listed are the five design constraint categories which are discussed further in the following paragraphs.

Design Constraints
Scientific and Engineering Understanding of Nature
Economics
Environmental
Institutional, Political (Social), Legal
Aesthetics

We also limit the discussion here to the general practice of coastal engineering. Part V-8 is completely devoted to special, U.S. Federal government planning requirements and design constraints.

(1) Scientific and engineering understanding of nature. The coastal setting is dynamic and influenced by land, water, and air interactions and processes. It is a regime of extremes, surprises, and constant motion as the coast responds to changing conditions.

(a) The *Coastal Engineering Manual* (CEM) demonstrates continued improvement in understanding and ability to analytically and numerically model nature. For example, Part III-3 discusses analytical methods to estimate sandy beach shoreline recession rates during storm events that will be useful later in this chapter. Part III of the CEM also introduces many new, dynamic, numerical models that simulate coastal hydrodynamics and sediment transport processes.

(b) CP Module. In V-1, the idea of a Coastal Processes Module, (CP Module) was defined as a repository of physical data and analysis tools relevant to the coastal problem. Wind, waves, currents, water levels, bathymetry, geomorphology, stratigraphy, sediment characteristics, sediment transport processes, etc. and the analysis tools (mainly numerical models) make up the CP Module that is employed many times in the design process (see Figure V-1-1, 2 and 3). However, a fully dynamic, three-dimensional, numerical model of water levels, waves and sediment transport to simulate bathymetric and shoreline change is still under development. It remains a long way from routine application for the functional design of coastal structures. An example would be the simulation of natural, sediment movement behind and through nearshore breakwaters for both normal conditions and storm events. The inability to accurately predict the short-and long-term impacts of coastal structures on the nearshore physical environment remains a design constraint in coastal engineering. Part of the difficulty is the stochastic variability of the natural environment.

(c) Empirical Simulation Technique (EST) methodology. Numerical models are deterministic tools that produce one solution for each set of boundary conditions. The EST procedure is the numerical, computer simulation of multiple, life-cycle sequences of systems such as storm events and their corresponding environmental impacts (Scheffner et al. 1997; 1999). Multiple life-cycle simulations are then used to compute frequency-of-occurrence relationships, mean value frequencies and standard error estimates of deviation about the mean. Using the EST procedure for a specific project generates risk-based frequency information that relates the effectiveness and cost of the project to the level of protection provided.

- A user's guide for application of the EST with examples is found in Scheffner et al. (1999). One example describes calculations of the frequency-of-occurrence relationship for storm-induced, horizontal recession of beaches and dunes in Brenard County, Florida. Previous references to the EST procedure are found in Part II-5 and II-8. See also Part V-1 for discussion.

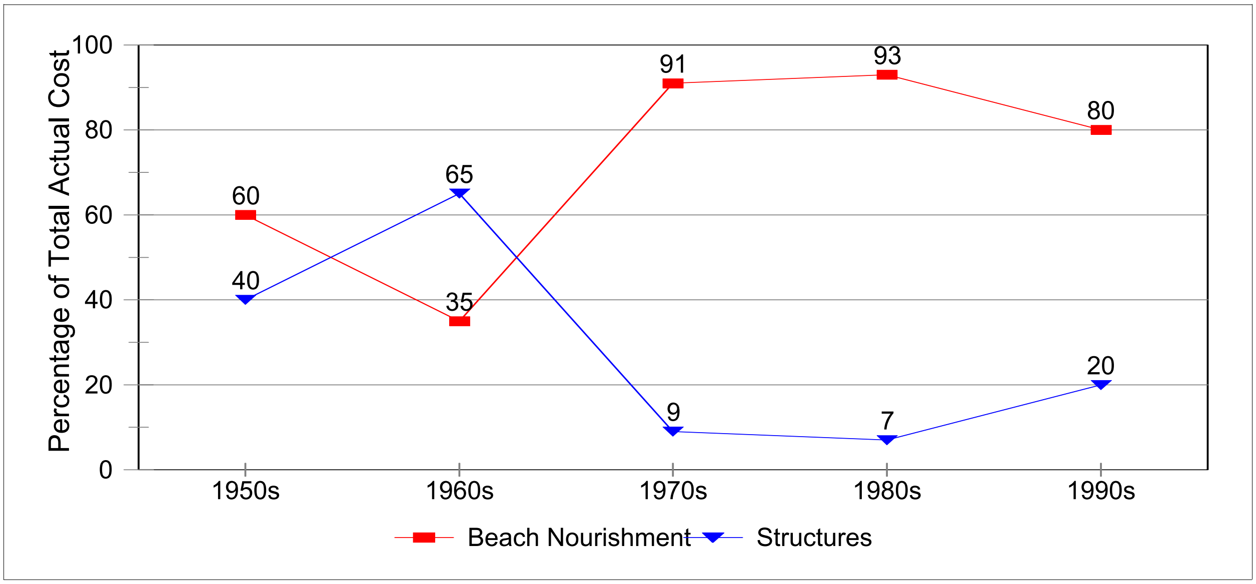

Figure V-3-3. Shift from hard (armored walls, groins, etc.) to soft (beach nourishment) alternatives by the Corps of Engineers (from Hillyer 1996)

- The Corps has specified the EST methodology as a requirement for the risk-based analysis in all shore protection studies (ER 1105-2-101; Thompson et al. 1996). The probabilistic design (functional, structural) of coastal structures remains a constraint, but recent advances such as the EST methodology are helping to produce designs that provide a realistic level of storm protection.

(2) Economics. A key constraint for each shore protection alternative is life-cycle cost. In general, the level of storm protection and, hence, costs (high, medium, low) can only be justified when the corresponding value of property and infrastructure to be protected (benefits) are comparable (high, medium, low). Costs are not subjected to any other constraints. Benefits, however, can be restricted and limited to only those that are perceived to benefit the funding authority. For example, see Part V-8 for the restriction on allowable benefits for Federal government-sponsored projects designed by the Corps.

(a) Cost. It is important to have a clear definition of all terms when discussing costs. Moreover, nothing lasts forever. Advocates for permanent, low cost, or retreat solutions for shore protection fail to understand the following and how they are applied in the professional practice of coastal engineering design economics.

- Costs: The monetary value required for a project. Without additional qualifying words, the word alone is confusing and subject to misinterpretation.

- Initial costs: The total expense for all initial construction and design costs of a project. The year of construction should be noted so that inflationary cost aspects can be estimated in the future. Distinction should be made between estimates and actual contract costs.

- Maintenance costs: The estimated annual expenses required to maintain both the functional and structural integrity of the alternatives which are altered by storm damage and natural processes. Both deterministic estimates and risk-based calculation methods can be employed. (see Part VI-7 for an example of the probabilistic method for rubble-mound breakwaters)

- Alteration/removal costs: The estimated expenses required to alter the design or completely remove the structure if there are significant, downdrift impacts. Evidence from postproject monitoring and decision criteria mechanisms are required for implementation. This cost has been ignored for most projects and could be included in the category of maintenance costs.

- Total, life-cycle cost The combined initial, maintenance and alteration/removal costs required over the design life of the project. Annual maintenance costs are usually converted to their present worth so that they can be directly combined with the initial construction costs. The present worth (value) is determined by multiplying the annual maintenance expense by the present worth factor, PWF. The PWF is a function of the design life and the interest (discount) rate. (See any standard engineering economics text).

- Design life: An estimate of the number of years of useful life of the structure/ alternative. Usually 25 to 50 years is employed for well-designed projects. Design life selection includes structural life of materials (structural integrity), functional life (usefulness), technical life (technologically up-to-date), and aesthetics. Design life is employed for the economic analysis of the present worth of annual maintenance cost for the total, life-cycle cost comparison of all alternatives. It does not mean the length of time the project will last in the field.

- Interest rate: The second variable required to calculate the present worth of the annual maintenance costs. Often, the rate employed is related to the current, bank loan rate for construction projects. It can also be set by government policy as discussed in Part V-8 for the Federal government.

- Damage: When energy levels in storms exceed the design levels, both structural damage and some loss in functional performance may occur. Repair is possible. Damage is an expected aspect of risk-based coastal design.

- Failure: When storms below the design level cause loss of structural integrity and/or functional performance. The design has failed and a redesign is needed before repair or reconstruction. Use of the word “failure” for loss of structural integrity or performance should be avoided until it can be proven that a design failure took place under specified storm conditions.

- Balanced design: The most economical balance between the initial construction costs and maintenance (damage repair) costs so that the total cost is a minimum. Initial costs increase as the level of protection for more powerful (but rarer) storms increases, but maintenance costs decrease because damage is less frequent. The classical U-shaped, total cost curves result. (See Part VI-7 for an example with rubble-mound breakwater design)

(b) Benefits. Storm damage reduction and coastal erosion mitigation are the two major benefits of shore protection. These two along with ecosystems restoration are the only benefits allowed by the Federal government for Corps projects as discussed further in Part V-8.

- Many other benefits exist. As seen in Figure V-3-3, since the 1960s, beach nourishment has been the selected alternative for shore protection. Substantial recreation and tourism benefits have resulted for local, state, and Federal governments. Waterfront property is generally of greater value and generates higher property taxes. Innumerable secondary (ripple effect) benefits result from the coastal, beach-related travel and tourism industry. The economic value of beaches has been well documented (Houston 1995a; 1995b).

- A good example is Miami Beach, Florida, which was renourished in 1979 by a joint Corps of Engineers - City/County government project costing $52 million. The capitalized annual cost is about $4 million and the project has lasted more than 20 years without the need to renourish the beach. Attendance at the beach increased from 8 million in 1978 to 21 million in 1983 (Houston 1995a). More than 2 million foreign visitors spend over $2 billion annually at Miami Beach (Cobb 1992). The Miami Beach experience is roughly $700 return in foreign exchange for every $1 invested in beach nourishment (Houston 1995a; 1995b; 1996).

- Beach nourishment can also enhance the natural environment. Widened beaches reduce the potential for new, tidal inlet formation during storms at narrow reaches of barrier islands. The economic losses to the protected bay environment (property, recreation, farming, fishing, infrastructure, etc.) can be estimated and added to the storm damage and other benefits for the impacted barrier island. In general, however, environmental benefits of the enhanced, flora and fauna habitat are difficult to quantify monetarily.

- All benefits are site specific. Here, we briefly outline the methodology commonly employed to determine storm damage reduction benefits. A key factor, as illustrated in Figure V-3-2 is distance between the reference baseline and the sea. Steps in the methodology are:

  - Make a structure inventory (residential, commercial, public). Employ aerial, orthodigital mapping and Geographic Information System (GIS) technology where possible and adapt new technologies.

  - Obtain software to calculate the depreciated replacement cost of the structures and content value.

  - Obtain the water level, storm frequency-of-occurrence data for the site, and accompanying wave and shoreline erosion data. The EST methodology previously discussed should be employed, whenever possible.

  - Obtain and run storm damage calculation models. Long-term erosion is included to estimated damages under changing future conditions. The key variables are water level and position of each structure in relation to the shoreline. Some models only treat property structure damage and others land and infrastructure (roads, etc.) damage.

  - Apply the models for both the without project conditions and for the alternatives and subalternatives design considered for shore protection.

- The result is the average, annual damages prevented (benefits) of each alternative. Differences for each alternative to prevent or reduce storm damage are quantified by this approach. Complete details can be found in Part V-8 where names and references for some of the software and models presently employed by the Corps are presented. In general, the state of art for these damage calculation models is less well advanced than for other areas of coastal engineering design.

(c) Benefit/cost ratios. A useful indicator of economic performance of each alternative is the benefit to cost ratio (BCR). As previously noted, the total, life-cycle costs do not depend on the other constraints, therefore remain constant. However, the benefits included in the ratio can be limited by the funding authority. Consequently, the BCR calculated can be significantly different depending upon whether all the potential benefits or only limited benefits are considered. Because the Federal government limits the benefits allowable to only storm damage reduction benefits, the total or true BCR is always greater than that specified for Corps projects. In effect, two BCR's exist.

- Federal government, $(BCR)_F$

$$(BCR)_F = \frac{\text{Storm damage reduction benefits}}{\text{Total, life-cycle cost}} \tag{V-3-1}$$

- Total, true $(BCR)_T$

$$(BCR)_T = \frac{\text{Total benefits}}{\text{Total, life-cycle cost}} \tag{V-3-2}$$

- Further details regarding the $(BCR)_F$ for Federal-sponsored projects and other methods to measure economic performance are discussed in Part V-8. The total $(BCR)_T$ is never calculated for Corps projects. Consequently, the local sponsors, general public, and media may not understand nor appreciate the true value of shore protection projects to their community. These institutional, political (social), and legal constraints are discussed further in the following paragraphs.

(d) Sea level rise. A detailed summary of present day knowledge of mean sea level change of the world's oceans is given in Part IV-1-6. Over the last 100 years, average, relative sea level rise has been 30 cm (3 mm/year) on the East Coast and 11 cm (1.1 mm/year) along the West Coast (excluding Alaska). The Gulf of Mexico coast is highly variable ranging from 100 cm (10 mm/year) in the Mississippi Delta plain to 20 cm (2 mm/year) along Florida's west coast (National Research Council 1987). Substantial local variability exists. The question remains as to whether these average rates will increase (substantially), stay constant, or decrease in the future. Three things remain clear, however. The existing rates of mean sea level rise at specific sites have not been a severe economic constraint for the shore protection alternatives selected. At many locations, anthropogenic effects (e.g., jettied tidal inlets) causing downdrift, beach erosion are clearly much larger than those occurring due to sea level rise. And finally, long-term, relative changes in sea level can be incorporated into storm surge analysis and the economic design of coastal structures.

(3) Environmental. A third major constraint of shore protection works is their impact on the environment. The Eastern Scheldt, storm-surge barrier shown in Figure V-3-1 was the focus of much discussion in the early 1970s. Environmental scientists favored raising the dikes around the periphery to maintain the saltwater ecology of the tidal estuary. Agricultural and water boards favored a solid dam across the mouth that would create an inland, freshwater lake. A compromise was reached: a storm-surge barrier with movable gates which stay open under normal conditions but are closed at very high storm-surge events. The final design, construction methods and equipment required much research and challenged the ingenuity and technical process of Dutch coastal engineers. In the final analysis, the environmental constraint, to maintain the saltwater ecology, dictated the final design. The additional engineering and construction cost proved to not be the deciding factor.

(a) Types of environmental concerns. As in the preceding example, modification of upland habitat such as land use, resting areas for turtles and shore birds, wetlands, flora and fauna beneficial to the ecosystem, threatened and endangered species, etc. can take place. The aquatic habitat can also be important, for example, water quality, aquatic species, benthic organisms, hazardous, toxic and radiological sediment in borrow areas, increased turbidity during dredging operations and wave climate alterations by sand volume removal in borrow sites, etc.

- These potentially negative impacts must first be identified. Detailed surveys and sampling investigations are conducted to catalog the species and habitats in the project area under existing conditions. Use should be made of previous studies and summary information. The U.S. Fish and Wildlife Service (F&WS) prepares a planning aid report for large Corps projects that detail existing fish and wildlife resources and their habitats. This report also identifies threatened and endangered species and critical fish and wildlife habitats. The National Marine Fisheries Services (NMFS), state and local resource agencies, and local universities may also provide valuable information.

- The offshore, sand borrow site is the greatest environmental concern for beach nourishment projects. New, benthic sampling and collection efforts are often needed to catalog existing species and habitat. Of concern are species capable of rapid recolonization, commercially important species, or protected species. These surveys provide data on abundance and diversity together with a complete list of all species present. This knowledge can be critical in borrow site selection and hence overall cost of the project.

- In most cases, an Environmental Assessment (EA) report is sufficient to demonstrate the minor environmental impact of shore protection projects. Rarely is a full, Environmental Impact Statement (EIS) needed which is time consuming and can be expensive. Corps project needs for an EIS are discussed in Part V-8.

(b) Impact on natural sediment transport system. The negative, downdrift impact on the local and regional sediment budget can be a key environmental constraint. These concerns are addressed in detail in Part V-3 for armored (Part V-3-2) and shoreline stabilization (Part V-3-3) structures and in Part V-5 for jetties at navigation inlets. A beach nourishment project has many positive, environmental impacts by bringing new material to sand starved beaches and expanding the beach habitat. Studies in turtle nesting areas have proven that renourished beaches increase the number of turtle nests (Broadwell 1991; Nelson et al. 1987).

(c) Mitigation. Procedures, or measures which avoid, minimize and/or compensate for negative impacts are defined as mitigation. Threatened and endangered species such as the piping plover, least tern, sea turtles, and whales required special consideration during the planning and construction stages of shore protection projects. Avoidance of negative impacts is achieved by scheduling construction activities at times when the species do not normally inhabit the project area. Piping plovers and least terns are most vulnerable during the nesting/fledging period from early spring to late summer. Disturbances on the beach cause the nest to be abandoned before the eggs hatch.

- Avoidance for sea turtles and whales is not practical for the southern section of the Atlantic coast because these species inhabit the area for most of the year. Minimization of negative impacts is achieved in various ways including monitoring to document contact; using deflectors on the dragarms and collection boxes on hopper dredges; and conducting turtle relocation projects. These techniques are approved by the National Marine Fisheries Service.

- Mitigation by compensation is employed when resource loss is unavoidable. The most common example is new wetlands construction to compensate for the wetlands area lost due to project construction. Some states require more new area constructed than lost and permit wetland banks that are used to pay for planned, future wetlands loss. New and rebuilt dunes are replanted with grasses to compensate for any plants lost during construction. Mitigation by compensation methods are normally carried out and completed during project construction.

- Ecosystem restoration projects result from habitat lost due to a previous activity such as construction of jetties at a tidal inlet and the long-term, downdrift erosion of the beach. Restoration and protection of unique species habitat could also be the objective. Normally, beach nourishment projects can be designed to meet these project objectives. Methods to quantify these environmental benefits are discussed in Part V-8 as applied by the Corps.

(4) Institutional, political, legal. A fourth area that has a formidable influence on the design process are the institutional, political (social), and legal requirements for all projects.

(a) Institutional (policies and guidelines). The Federal objective of water and related land resources project planning is to contribute to the national economic development (NED) consistent with protecting the nation's environment. Applicable executive orders and other Federal government policies and guidelines as planning requirements are discussed fully in Part V-8. The Corps is responsible for shore protection designs of the Federal government. The Corps District Office engineers with the possible aid of the Coastal Hydraulics Laboratory (CHL), Engineer Research and Development Center (ERDC), do most of the design work. Some design work is performed by the private, civil engineering consulting firms. No general guidelines exist as to when and how the private sector, coastal engineering community participates in the design process for the Federal government.

- Other Federal agencies are responsible for some aspects and alternatives for shore protection. A National Flood Insurance Program (NFIP) was established in 1968 to help reduce the Federal share of costs in connection with flood losses. The NFIP is operated by the Federal Insurance Administration, a division of the Federal Emergency Management Administration (FEMA). An essential component for implementing the NFIP is the Flood Insurance Rate Map (FIRM) which delineates special flood hazard areas and insurance risk zones. These maps are prepared by FEMA's mitigation division. Places subject to flooding at the annual, one percent exceedance probability level are designated as special flood hazard areas. The associated recurrence interval is the so-called, 100-year flood. Use of the 100-year flood designation is discouraged. Many people believe that a 100-year flood happens only once every 100 years. Some areas have experienced flooding at this probability level in consecutive years. The FEMA flood hazard zone maps include special V-zones for both flooding and significant wave energy to cause structural damage. Construction standards (where applicable) and flood insurance rates are usually higher for structures located in V-zones.

- Zoning laws and improved building standards are then implemented by coastal communities based on the FIRM and designated hazard-prone areas. One common standard is the requirement that all, first-floor living quarters of new construction be set at least one foot above the mapped elevation of the one percent chance flood.

- Since 1982, all NFIP policies are actuarial, i.e., the flood insurance policy's annual rates fully reflect the buildings risk of flooding. No taxpayer subsides are required. Presently, about 23 percent of structures vulnerable to flooding damages are covered by the NFIP. And, only 3 percent of these NFIP policies are in coastal communities. These coastal communities generate more premium income that they have received in loss claims (Houston 1999).

•Beaches serving as flood protection works are eligible for disaster relief from FEMA provided the relief is assigned public beach facility status. To qualify, it must have a period renourishment program for long-term maintenance. The local government project sponsor must restore the beach to its normal design shape (template) and pay for the cost of replacing sand eroded prior to the storm. Since natural beach rebuilding begins after the storm, it is not clear what time frame is employed to define the storm erosion volume.

- Several states have established construction setback lines to reduce damage in areas subject to coastal erosion and shoreline retreat. The setback line position is often calculated as some multiple of the annual erosion rate or a specified distance from a contour location in a particular year. In Florida, the line location is based on many factors, namely long-term erosional trends, short-term storm effects, rare water levels at the one percent chance, annual exceedance level, wave uprush, dune line position, wind forces and existing development. In Delaware, 1979 aerial photography has been employed and the restriction line set 30.48 m (100 ft) landward of specified contour elevations, dune toes, or edge of the existing boardwalk structure. These development restrictions affect the without-project calculation of storm damage benefits discussed in Part V-3-1. If homes and structures are not able to be repaired or replaced after a storm by FEMA or state policies, than this will change the without-project estimate of benefits. See also Part III-5-13 for a discussion of setback lines for cohesive shorelines.

(b) Political (social well-being). Specific national policies and laws change as administrations and public interests change. A diverse and broad range of coastal system users with varying economic, social, and environmental expectations and goals exist. Although there have been shifts in the national policy for shore protection by the Administrative Branch of the Federal government, the legislative branch controls the authorization and funding of all Corps projects. Congress has continued to approve and fund the beach nourishment alternative. Shore protection in the U.S. remains political, fragmented, and controversial for a variety of reasons that are further elaborated in Part V-8. National plans for beach management and shore protection do not exist.

- Each project must consider many social aspects.

  - Local, regional and state plans for the coastal zones

  - Public health, safety, and social well-being, including possible loss of life

  - Community cohesion

  - Availability of public facilities and services

  - Potential adverse effects on property values and the tax base

  - Displacement of people, business, and livelihood

  - Disruption of normal and anticipated community and regional growth

  - Sufficient parking and public transport

  - Sufficient dune crossovers

- Public access and safety during construction

- Access for people with disabilities

- Interruption of recreation

• Cultural resources must also be considered.

• Coastal project construction has the potential to severely impact important cultural resources. Project activities such as offshore sand borrowing can damage or destroy important historical sites related to the region's maritime history. Shipwrecks, native American Indian, and prehistoric sites are typically of interest. Investigations by archaeologists to identify cultural resources in the project area provide data necessary to evaluate site significance and potential project impact. Close coordination with the state Historic Preservation Office is necessary for compliance with the National Historic Preservation Act of 1966.

• The politics surrounding shoreline erosion and measures for mitigation provide a wealth of fascinating reading material. For example, the Westhampton groin field on the south shore of Long Island, New York (U.S. Army Engineer District, New York, 1958: Heikoff 1976; Kassner and Black 1983; Nersesian, Kraus, Carson 1992; Spencer and Terchunian 1997; Terchunian 1988) is a classic example of a political decision that significantly altered the original design. The groin field was built in two stages, with 11 units constructed in 1964/65 and four more in 1970/71. It was a Corps project authorized by Congress in 1960. The project area extended from Fire Island Inlet east to Montauk Point and called for beach fill and groins as needed starting at the west end since the natural, net drift of sand was from east to west. A winter storm in 1962 breached the weakened barrier island at Westhampton. Local interests including the Suffolk County government lobbied for and eventually convinced the Corps to construct the groins in reverse sequence, from east to west. In addition, the groins were not filled with sand when constructed and construction was stopped in the middle of the project for political reasons. The result was a massive sand trap along Westhampton that starved the downdrift (westerly) beaches. The interruption of natural sand transport by Shinnecock and Moriches Inlet and the Westhampton Groin Field has accelerated erosion on Fire Island at the west end of the system (Kana 1999). A lawsuit by Fire Island property owners has resulted against the Corps (see Spencer and Terchunian 1997 for more details and reference). The legal constraint has long been a factor in coastal, shore protection design.

(c) Legal (laws). Congress, through passage of the biannual Water Resources Development Acts (WRDA), authorizes studies and funds construction of Corps projects. Sections of this law also include special investigations and establish cost-sharing formulas between the Federal government, state and local interests. For example, in the 1998 WRDA, the cost-sharing law was changed to 50 percent Federal and 50 percent from local/state interest.[1] As a result, some states have passed laws and statues to provide an annual source of funding for the increased cost of participation in Federally-authorized projects.

• The Coastal Barrier Resources Act (CBRA) was passed in 1982 to minimize loss of life, damage to fish, wildlife and natural resources, and wasteful expenditures of Federal revenues on Atlantic Ocean and Gulf of Mexico barrier beaches. The goal is to restrict all Federal government expenditures and assistance that aid development on the coastal barriers. For example, the CBRA relies on the National Flood Insurance Program to discourage building by prohibiting sale of Federal flood insurance in areas covered by the act. The CBRA does permit Federal funding for shoreline

[1] Previously, the formula was 65 percent Federal, 35 percent state/local.

stabilization by nonstructural projects that mimic, enhance, or restore natural stabilization systems, i.e., beach nourishment projects. Federal expenditures are also allowed for the study, management, protection, and enhancement of fish and wildlife resources and habitats.

- The CBRA is one of many Federal laws designed primarily to protect environmental and cultural resources. A partial list includes the following:

  - Archeological Resources Protection Act
  - Clean Air Act
  - Clean Water Act
  - Coastal Barrier Resources Act
  - Coastal Zone Management Act
  - Disabilities Act
  - Endangered Species Act
  - Estuary Protection Act
  - Federal Water Project Recreation Act
  - Fish and Wildlife Coordination Act
  - Land and Water Conservation Act
  - Marine Protection, Research Sanctuaries Act
  - National Historic Preservation Act
  - National Environmental Policy Act
  - Rivers and Harbors Act
  - Watershed Protection and Flood Prevention Act
  - Wild and Scenic River Act

- All shore protection projects must apply for and receive a permit from the USACE prior to construction. This permit is pursuant to Section 10 of Rivers and Harbors Act (1899) and Section 404 of the Clean Water Act (1977). The permit process considers and evaluates many factors, including effects on conservation, economics, aesthetics, general environmental concern, wetlands, cultural values, fish and wildlife resources, flood hazards, flood plain usage, land use, navigation, shore erosion and accretion, recreation, water supply and conservation, water quality, energy needs, safety, food and fiber production, mineral needs, and welfare of people and society. Some states have a Joint Permit Application for local boards, state agencies and the Corps of Engineers permit. This method saves considerable expense and time in that only one permit application is required to meet the needs of all three levels of government review of the proposed project.

- Some states (North Carolina, Maine) have passed laws banning the use of armored structures (seawalls, bulkheads, revetments) and shore protection on their ocean coasts. South Carolina only bans armored structures and other coastal states are considering similar laws. Florida and California have adopted sand mitigation policies and procedures to permit seawall construction but require the annual placement of sand to compensate for that trapped behind the structure. Further details on seawall and beach interactions are summarized in Part V-3-2.

- Laws for property boundaries at the land-water interface are complex and vary from state to state. A 26-article series entitled "The Law of the Sea in a Clamshell" explaining the applicability and diversity of laws pertaining to the shore has been published by the American Shore and Beach Preservation Association in the magazine *Shore and Beach* (Graber 1980). Clear and legally defendable knowledge of property ownership must be an early step in the design process for coastal protection works.

(5) Aesthetics. A final and especially challenging area in design pertains to the sense of beauty and accepted notions of good taste. Many people feel that natural shorelines (e.g., wide, sandy beaches, rocky cliffs, or vegetated marshes and trees, etc.) are more aesthetically pleasing than ones artificially manipulated for shore protection. An uninterrupted, uncluttered, and natural view of the sea is desirable for most people. Therefore, when possible, an aesthetically balanced and consistent appearance, replicating natural systems is preferred.

(a) The "do nothing" alternative may result in a destructive wake of debris from flooding and wave damage that is visually disturbing for days or weeks following a storm. Some alternatives (e.g., geotextile bags filled with sand) will not survive medium level storm events and leave a debris-strewn beach.

(b) Aesthetics played a major role in selection of the final design for the new, hurricane protection, seawall/boardwalk at Virginia Beach, Virginia. The initial design by the Corps was a massive, curved, concrete seawall patterned after the one in Galveston, Texas. The City of Virginia Beach is a popular tourist, recreation beach and the promenade (boardwalk) features a key aspect of the design. The city rejected this initial design for aesthetic and tourist-economy reasons. First floor hotel guests and restaurant patrons would not be able to see the ocean on the south end. Their view was blocked by the crest elevation of the proposed seawall. The revised design lowered the seawall elevation, modified the structural design, added interior stormwater drainage to accommodate additional overtopping, and widened the nourished beach in front to mitigate storm energy. An artist's perspective and aerial photo are found in Part V-3-2a (Figure V-3-6). The constraints that dictated the final design were aesthetics and the need to accommodate the beach-driven, tourist industry.

(c) Engineering is not applied science. Our limited understanding of nature is one constraint, but it is far from the only one, seldom the hardest one, and almost never the limiting constraint for coastal engineering design.

V-3-2. Coastal Armoring Structures

a. Types.

(1) Seawalls and dikes. The primary purpose of a seawall (and dike) is to prevent inland flooding from major storm events accompanied by large, powerful waves. The key functional element in design is the crest elevation to minimize the overtopping from storm surge and wave runup. A seawall is typically a massive, concrete structure with its weight providing stability against sliding forces and overturning moments. Dikes are typically earth structures (dams) that keep elevated water levels from flooding interior lowlands.

- Various types of seawalls and dikes are depicted in Figure V-3-4. When vertical, they are labeled nonenergy absorbing, whereas if with a sloping surface or rubble mound, they absorb some energy (Pilarczyk 1990). The front face may also be curved or stepped to deflect wave runup. Typical damage modes for seawalls include: toe scour leading to undermining; overtopping and flanking; rotational slide along a slip-surface below and shoreward of the seawall; and corrosion of any steel reinforcement. Vrijling (1990) discusses 14 damage/failure mechanisms for dikes including "stability of the protective revetment." Part VI presents details for functional design.

- Construction of the massive, concrete seawall to protect Galveston, Texas, against overflows from the sea began in 1902, in the aftermath of the major hurricane of September 1900. Over 6,000 (16 percent) of the citizens lost their lives. An original construction photo (top) and chronology of seawall and embankment (dike) cross-section development (bottom) are shown in Figure V-3-5 (from Davis 1961). Major features are the wood piles, a sheet-pile cut-off wall, riprap toe protection, and the curved face to deflect wave runup. Modification and extension occurred in 1909, 1915, 1926, and the last extension to the west completed in 1963. In the almost 100 years of existence, many lives and millions of dollars of property damage have been saved by this project (Davis 1961).

- The City of Virginia Beach has opted for a low-crest elevation, sheet-pile, concrete cap seawall that also serves as a new boardwalk. Figure V-3-6 displays an artist's perspective (top) with cross section and an aerial photo (bottom) of a recently (1998) completed section. Construction of the newly designed, interior drainage system with pumping stations for an ocean outfall and a widened sandy beach will complete the project in 2002.

- Part VI-2 also discusses many other typical cross sections and layouts of seawalls and sea dikes.

(2) Bulkheads. These are vertical retaining walls to hold or prevent soil from sliding seaward. Their main purpose is to reduce land erosion and loss to the sea, not to mitigate coastal flooding and wave damage. For eroding bluffs and cliffs, they increase stability by protecting the toe from undercutting. Bulkheads are either cantilevered or anchored sheet piles or gravity structures such as rock-filled timber cribs and gabions. Cantilever bulkheads derive their support from ground penetration; therefore, the effective embedment length must be sufficient to prevent overturning. Toe scour results in a loss of embedment length and could threaten the stability of such structures. Anchored bulkheads are similar to cantilevered bulkheads except they gain additional support from anchors embedded on the landward side or from structural piles placed at a batter on the seaward side. For anchored bulkheads, corrosion protection at the connectors is particularly important to prevent failures. Gravity structures eliminate the expense of pile driving and can often be used where subsurface conditions support their weight or bedrock is too close to the surface to allow pile driving. They require strong foundation soils to adequately support their weight, and they normally do not sufficiently penetrate the soil to develop reliable passive resisting forces on the offshore side. Therefore, they depend primarily on shearing resistance along the base of the structure to support the applied loads. Gravity bulkheads also cannot prevent rotational slides in materials where the failure surface passes beneath the structure. Typical bulkheads are shown in Figure V-3-7.